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WSTIAC

WEAPON SYSTEMS TECHNOLOGY INFORMATION ANALYSIS CENTER

Progress in Directed Energy Weapons

Part III: Pulse Power for DEW

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Contents

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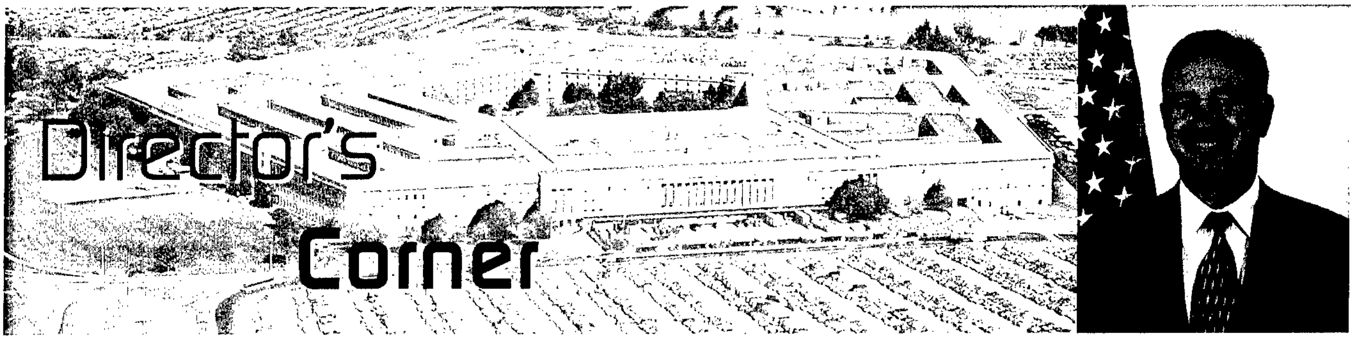
Introduction

This is the third of a triad of articles on Directed Energy Weapons (DEWs). The first article by Mark Scott covered High Energy Laser (HEL) Weapons (Vol. 4, No.1, Spring 2003), and in the second article, by the present author, we reviewed Radio Frequency DEWs, most often referred to as High Power Microwave (HPM) Weapons, which constitute the second largest R&D effort in the DEW field. Since there are other possible types of DEWs, (such as Relativistic Particle Beams (RPBs), etc.), the previous articles set forth a few definitions that differentiated between them, especially with respect to their particular applications and target effects, which bound their usefulness to the warfighters and the platforms they must use for the whole battlespace. The output parameter limits placed on the various technologies by the operational requirements and environments, in turn, produced "design drivers" that defined the total integrated DEW system. One of the major design drivers (perhaps the most important after the target lethality requirements) is the electrical and pulsed power required by all DEWs. The present article will review, what to this time may be called the "Achilles heel," of DEWs, i.e., the usually large and heavy Pulsed Power Systems that are necessary to provide the tremendous power and energy requirements of DEW systems, as well as the power conversion and conditioning components and subsystems between the prime power source and ultimate DEW source and radiator, whether it be laser, microwave or other type of DEW.

Pulsed Power for DEWs - Background

Although perhaps not as glamorous a subject to most as the Directed Energy Weapon (DEW) sources themselves, unfortunately, as noted above, the Pulsed Power Subsystem (PPS) usually represents the largest payload weight and volume penalty in the overall DEW system, and therefore requires serious attention by any researcher or developer, and ultimately by the end user in the latter's deployment and combat considerations. To this end, we shall endeavor to define and give as generic a picture as possible of what represents a PPS and what critical path components go into such an important piece of the overall DEW system itself. To do this, we must first give some indication of what is "Pulse Power" and what differentiates pulse power from continuous power, especially with respect to DEWs:

(continued on page 3)



Director's Corner

by Mr. Gary J. Gray

Ladies and Gentlemen:

With this newsletter, we are asking our existing and first-time readers for their opinions. Our first-time readers are made up of many of my former leaders and colleagues that will be seeing the WSTIAC newsletter for the first time.

To our collective readers, we value your opinions and it is our belief that you may find that we can provide information, products, and services that can help the Department of Defense execute its complex mission more effectively and efficiency. First, we want to see if you agree. Second, we would like to get your help to continue to improve.

If you are willing, please complete our online survey at **http://wstiac.alionscience.com/gac/jsp/survey/gacsurvey.jsp?12**

Our first 1000 respondents to our online survey will get a Global Positioning System (GPS) Error Calculator. It can be used to design a complex weapons system or to determine how far your new GPS-equipped vehicle may be off course.

To help you understand what we are about, below is a sampling of our tasks:

- Supporting the Director of Defense Research and Engineering's tri-Service Energy and Power Technology Initiative.
- Supporting Army's Objective Force air and missile defense requirements for the 2015-2020 timeframe
- Supporting the transformation to the Global Information Grid and the Defense Spectrum Office
- Developing an armed Unmanned Aerial Vehicle demonstration for the Army
- Evaluating sensor-based systems to improve mine/minefield detection
- Supported Red team threat target selection for smart munitions against Future Combat System units
- Developed a comprehensive assessment of Anti-Jam Techniques for GPS
- Developed the Intelligent Bridge Assessment, Repair and Retrofit Tool to help the soldier determine bridge load assessments and vulnerabilities.
- Developed Future Strike Fighter trade studies.

As you can see, the type of tasks we can provide is very broad and covers a wide variety of technologies. I hope you get a sense of the work and the expertise that WSTIAC can provide to help solve your difficult problems. If you want to know more, please call or email me at 703 933 3362 or gjgray@alionscience.com

Thank you again for your time.

Gary J. Gray
Director

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What is "Pulse Power"?

- The application of large stored energies, $\mathcal{E}$, to a load in time T
- High powers are produced, since $\mathcal{E}$ =10 - 10,000,000 Joules, and $T < 1$ microsecond (typically)
- Example: 1000 J released in 0.1 microseconds = 10,000,000,000 Watts = 10 large continuous power plants

As can be seen by the huge *peak* powers quoted above, it is obvious that DEWs require high *average* power inputs to be converted to extremely high *peak* values, in order for the DEW sources (whether lasers, RF/HPM, particle beams, etc.) to produce their equally tremendous output radiative powers. This is done by some form of *pulse compression* or *peaking* circuit, which forms a very important part of the overall PPS component train. This is illustrated below (Fig. 1) in a "typical" example of what are perhaps the most important basic principles to be learned in pulse power - that of *pulse forming* or *pulse compression* and, subsequently, that of *impedance matching* to the DEW source:

Typical Power Flow Requirements

- Deliver a few kilojoules (kJ) to a DEW source, typically producing an electron beam (CPB or RF-DEW) or laser pump source or amplifier :
    - Typical values: V ~ 0.5 MV, I ~ 20 kA
    - Power ~ 10 GW ⇔ A 60ns pulse contains ~ 600 Joules (About 1/5 power produced by Mid-Atlantic Utilities)
- Energy Storage, Power Multiplication and Pulse Compression:

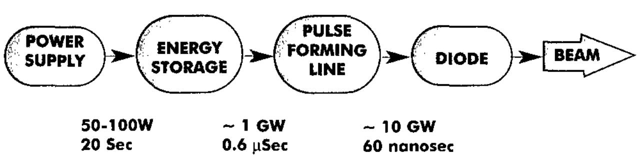


Figure 1.

In the example shown in Fig.1, one can see that, after the first block, which represents a more or less conventional (but probably customized) power supply that converts the "prime" power voltage and current (say, from an AC Motor-Generator or "wall-plug" value, not shown in Fig. 1) to an indicated DC voltage and current, the power supply then "charges" an energy storage subsystem or component at this "low" power input of only 50-100 Watts, but for a fairly long period of 20 seconds. The energy storage element can be any of several types or combination of components, but it is usually made up of either capacitors or inductors, for the eventual very high peak powers required by most DEW sources.

After a natural and/or designed "charging" time, through some sort of "switching" circuit or series of switching components (another very important technology that will be discussed in some detail later), the power in the storage element is released (or "switched-out," or "dumped") in a much shorter time - in this case in 0.6 microseconds (1 μsec = 10^{-6} sec = 1 Billionth of a second). Since the overall energy losses (say, due to ohmic, or resistive, heating) are very low in this process, and are not counted in this example, the power, being the energy released into the next stage per unit time, is conserved (remains constant), and is now "compressed" into a very much higher "peak" value of around 1 Gigawatt (1 GW = 1 Billion or 10^9 Watt)! Although already at a very high value, DEW sources most often require even further compression/peaking, and sometimes further "shaping," so that the final voltage and/or current pulse applied to the DEW source generating components results in the most efficient transfer of "pulse power" to output "radiative" power by the DE source. This latter transfer process is sometimes referred to as "impedance matching," in which only a theoretically maximum amount of the voltage and/or current pulse can be effectively transferred to the DE source.

The next stage in our pulse power example, the "Pulse Forming Line" (PFL) subsystem, can be an actual transmission line (or set of "lines" or cables), but is quite often just another set of capacitors and inductors arranged in a specific way (then becoming a Pulse Forming "Network" or PFN) to further tailor or "shape" the pulse for better matching to the final source stage. This PFL/PFN stage is also often termed, because of its function, a "pulse conditioning" or a "pulse modulation" stage. Some examples of the most common types of these will also be given in the following. This final stage in the pulse forming train results in our example in another order-of-magnitude increase in the *peak* power up to 10 GW, as a result of the shortening of the pulse in this case by *four* orders-of-magnitude, from 0.6μsec down to 60 nanoseconds (1 ns = 10^{-9} seconds)!

Pulse Power for DEWs - Energy Storage Subsystems

The fundamental principles of capacitive and inductive energy storage are illustrated in Fig. 2 below, where it is shown that each is utilized and, in fact, requires either a high voltage-low current power supply or vice versa, respectively. In the case of the capacitive energy storage example at left, "C" is most likely a bank of capacitors (i.e., a capacitor bank or CB), adding their individual capacitance to the total, thereby increasing the energy storage capacity. While switch S is open, current flows through the "charging" (or current "limiting") resistance R from the prime power or generator source, until the capacitor bank is fully charged to its maximum capacity, which then (assuming that its "hold-off" voltage is sufficient to avoid high-voltage breakdown of the internal dielectric insulator material in the capacitors) decreases the charging current to zero. At such time as is required by the user or control electronics, switch S is closed to initiate the sequence of discharging the energy stored in the CB to the next stage in the PPS or directly to the DEW (or any other kind of electrical load), if the PPS is somehow already matched to the load impedance.

Energy Storage
Capacitive - Closing Switch
Inductive - Opening Switch

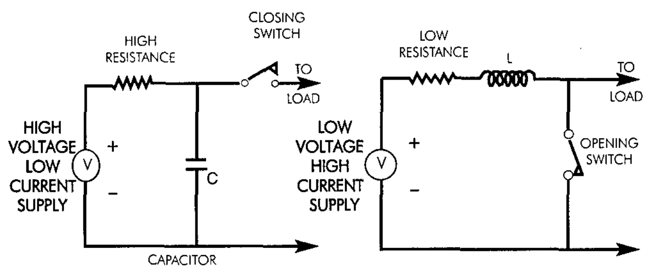


Figure 2.

The inductor, or coil, example on the right of Fig. 2 represents a virtual opposite to the capacitive energy storage system on the left, especially in the physics of their charging and discharging mechanisms. For capacitive storage, the energy is stored in the *electric* fields produced by the opposite electric charges on the "plates" or conductors separated by the dielectric medium of the individual capacitors. It is this electric charge that provides the voltage in parallel across the load, which, when connected to the load by closing the "closing switch," provides the electromotive force, or EMF, that produces, in turn, the current through the load. In the inductive case, however, the energy is stored in the *magnetic* field of the inductor, or coil, which is produced by the low-voltage, high-current supply passing through the *low* "charging" resistance and then through the inductor and closed *opening* switch and back to the power supply, thereby completing the closed circuit. Magnetic fields around conductors, which are maximized by wrapping conductors into various coil shapes, only exist as long as the current persists; so, unlike the energy stored in the electric fields of the CB, which will remain more or less intact for long periods (until leakage reduces it over time), the coil or inductor example must be discharged virtually immediately after it reaches its maximum designed value of magnetic field energy, so that the high current power supply and the closed *opening* switch, conductors, and other components do not exceed their own breakdown design values. When the opening switch is opened in the inductive circuit, the magnetic field energy in the inductor L is released (or re-routed) to the load. As anyone who has flipped on a light switch in the dark knows, there sometimes can be a substantial spark emanating from the switch. This is an even larger problem when one is trying to interrupt a circuit carrying the very large (sometimes Megamps = 1 million amps) currents required of DEW sources for very brief times (as with Explosive Driven Pulse Generators, which will be discussed later), and some process for quenching or extinguishing these large and dangerous arcs must be provided in the switch design.

Pulse Power for DEWs - Energy Storage/Power Conditioning Subsystems

We have been discussing CBs and inductors as both energy storage and pulse compression or "power conditioning" elements of our PPS, and noted two major categories - PFLs and PFNs for the latter. We have also discussed the fact that there is a maximum amount of energy that can physically be transferred, *if* certain conditions of impedance matching exist. All of this is summarized in the following:

Energy Storage/Power Conditioning - Line Type Pulser

- The energy is stored in a continuous or lumped element (i.e., "artificial") transmission line
- Lumped elements serve as energy storage elements, as well as pulse-shaping elements during discharge - this is then called a Pulse Forming Network or PFN
- Two classes of Line Type Systems:

Voltage fed	Current fed
W E = ½ CV²	W B = ½ LI²
Closing switch used	Opening switch used

- Voltage fed is more common
- If load impedance matches the line impedance:
  V LOAD = V CHARGE / 2 (Maximum)

So, how does the PFL or PFN actually "shape" the pulse, and how does one "match" the impedance of the former to the load? The answer to the first question is illustrated in Fig. 3 below, where a power supply is seen to be applying a charging voltage, V_C, through a charging resistance to a coaxial line of length ℓ. When the switch is closed, the charged line dumps its energy at voltage V_L across the load, which here is represented as a resistance R, equal to the characteristic impedance of the line, Z_0. The two graphs below the schematic indicate the voltage variation over time at the end of the line and across the load, respectively. In the top graph, the applied voltage is shown at the charging voltage, V_C (represented by the original "step" voltage, due to the charge on the line), until at time t_0 the switch is closed and the charged line dumps its energy into the load, and the voltage drops to a value equal to one-half of its original value, because the line is "terminated" in a resistance equal to the line's characteristic impedance.

Physically, this occurs because, when the line is suddenly terminated in $R_L = Z_0$, half of the static electric field due to the charges on the line is converted into a dynamic electric field by means of a time-varying magnetic field, which can be calculated by means of Maxwell's electromagnetic equations. Another way of putting it, is that one-half of the initial charge voltage is converted to a traveling wave within the pulse risetime (which is usually not considered in simple circuit theory), and one-half remains as a static electric field with the charges on the line. An electromagnetic voltage "wave" reflects back toward the source end of the line, opposite in phase from the original traveling wave with amplitude one-half of its applied value, thus canceling half of the applied pulse amplitude (when the pulse is reflected from the "open" end, the traveling-wave voltage remains at one-half the source voltage, but the static electric field and charge are reduced to zero). The time it takes for all this to occur (the *pulselength*, τ) depends on the physical and material properties of the line, as given by its length, permeability (magnetic properties/constant, μ) and permittivity (dielectric properties/constant, ε), as shown in the equations on the right. The resulting pulse now looks like the one in the bottom graph, for the values of relative permeability and permittivity shown, after the reflected negative pulse has re-reflected from the source and essentially cancelled the pulse front end.

Line Type Pulser - Pulse Forming Line (PFL)

- 1 meter coaxial cable corresponds to about 5ns delay
- Pulse forming lines, PFLs, are used to generate "square" pulses with durations usually less than several 10's to 100's of nanoseconds

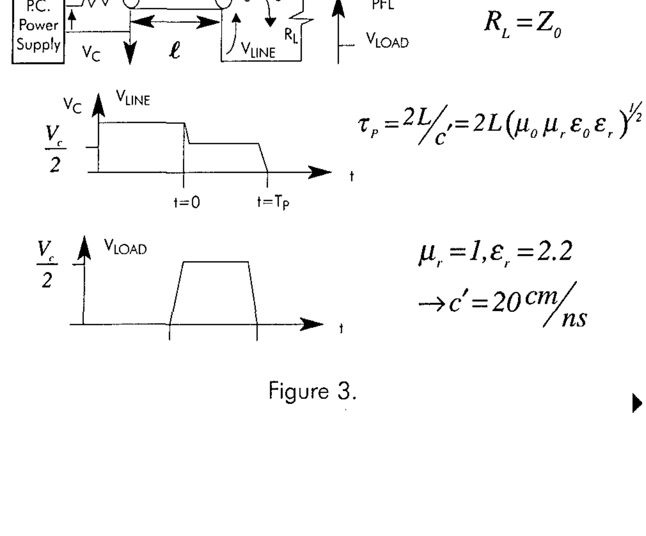
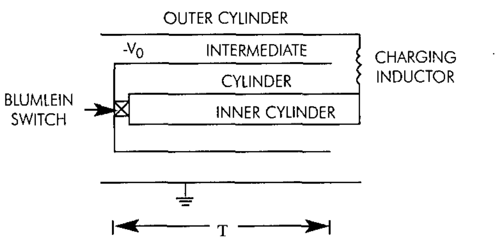


Figure 3.

This produces the usual "square-wave" type of pulse, unless some resistive and/or radiative losses are included, which leads to the trapezoidal shape shown. The resulting pulselength is twice the delay time of the line.

The importance of the above discussion is that these fundamental principles and mechanisms provide the means by which almost all PPS energy storage, pulse shaping (peaking, compression, modulation, etc.) and power multiplying circuits operate. For example, in order to not be restricted to having just half the applied voltage of a pulser appear at the load, or DEW source, one can use the traveling voltage (and current) waves explained above in a Blumlein Circuit, which utilizes the reflections from an open end of multiple concentric coaxial lines to double or add at each reflection, much like a sound wave reflects from the open end of an organ pipe, adding up to give a loud resonance. This is shown in Fig. 4 below.

Voltage Multiplication - Blumlein Circuit



Advantage - Full, rather than half charging voltage at load.

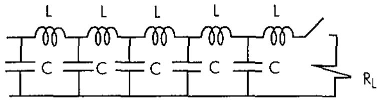
Figure 4.

In this case, a fast acting switch acts just as the traveling pulse arrives at one end to change the state from a closed to an open circuit, so that the reflected pulse adds, rather than cancels, the outgoing pulse, thereby doubling the pulse amplitude at each reflection, as many times as is either necessary, or as can be handled by the high voltage limits of the circuit and its components.

So far, we have been discussing the simplest form of pulser, that of a Pulse Forming *Line*, or PFL. However, as mentioned above, if the capacitance and inductance per unit length *distributed* along the transmission line is replaced by *lumped* components, i.e., actual capacitors and coils, then one has what is called a Pulsed Forming *Network*, or PFN. This configuration has many advantages - especially the power handling and energy storage capabilities - and is illustrated in Fig. 5 below, with the equations indicating how its design and output parameters are calculated:

Line Type Pulser - Pulse Forming Network (PFN)

- Pulse Forming Networks, PFNs are used to generate "square" pulses with durations grater than 100s of nanoseconds
- PFNs are lumped elements transmission lines
- Example: Rayleigh line of lumped T-line (equal caps and inductors)



$L_T = nL$

$C_T = nC$

$L_T = \frac{T_P}{2} Z_{PFN}$

$C_T = \frac{T_P}{2Z_{PFN}}$

$$Z_{PFN} = \sqrt{\frac{L_T}{C_T}} = \sqrt{\frac{L}{C}} \cdots = \sqrt{\frac{L/length}{C/length}}$$

$$f_{max} = \frac{1}{T_{rise}} \approx \frac{2}{\pi\sqrt{LC}}$$

Figure 5

Many other configurations of the basic Rayleigh, or lumped T-line, shown in Fig. 5 are possible, each with source and load connection characteristics that benefit the particular application. Some of these different configurations are shown in Fig. 6 below:

Line Type Pulser - Pulse Forming Network (PFN) Types

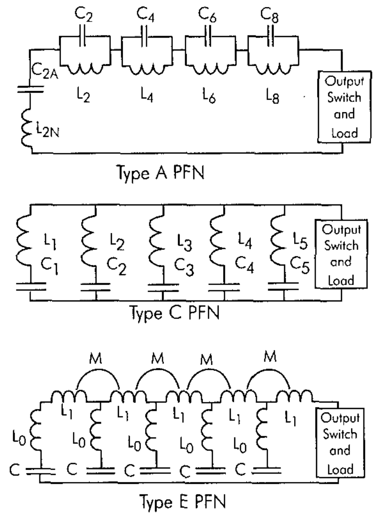
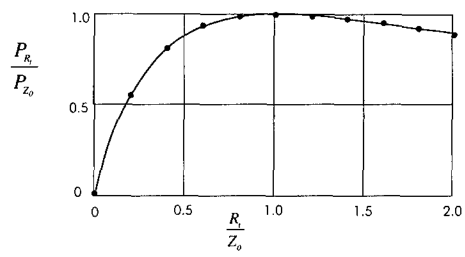


Figure 6

Up to this point, we have also been only concerned about an *exact* match of the pulser to the load, in order to obtain maximum energy transfer between them, for consequent maximum efficiency of the PPS. However - especially since this is rarely obtainable in practice - it is useful to point out here that an *exact* match is not really necessary, since there is a considerable variation about the matched situation that still allows for high values of energy transfer efficiency, as is shown by the relatively flat portions of the impedance-matching curve in Fig. 7 around the $R_L / Z_0 = 1$ (matching) midpoint:

Line Type Pulser - Effect of Load

Effect of load mismatch on power transfer



Mismatch of 20-40% is not very critical for the sake of higher power delivery.

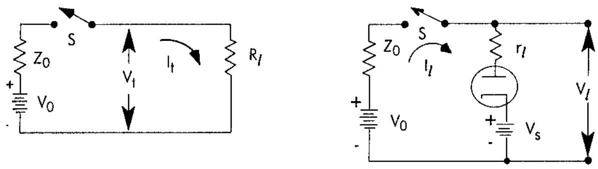
Figure 7

The main reason for mismatches of the pulser to the load is that the load itself is almost always nonlinear in one form or another - i.e., its resistance, or impedance (usually complex, in the algebraic, as well as physical sense) - varies with the applied voltage and/or current. In Fig. 8 below, a simple resistive load is compared with a nonlinear RF-DEW, or HPM, load (a magnetron in this case), where it is seen that the impedance matching condition for the nonlinear magnetron is a function of the applied and the cathode bias voltages (along with the plate resistance).

However, for both cases, the power delivered to the load is given by the same relation for the matched condition.

Line Type Pulser - Biased Diode Load

$$Z_0 = R_l \quad \leftarrow \text{ matched for } \rightarrow \quad Z_0 = r_l \cdot \frac{V_0}{V_0 - 2V_s}$$



Simplified equivalent circuit for a line-type pulser with a purely resistive load

Simplified equivalent circuit for a line-type pulser with a biased-diode (magnetron)

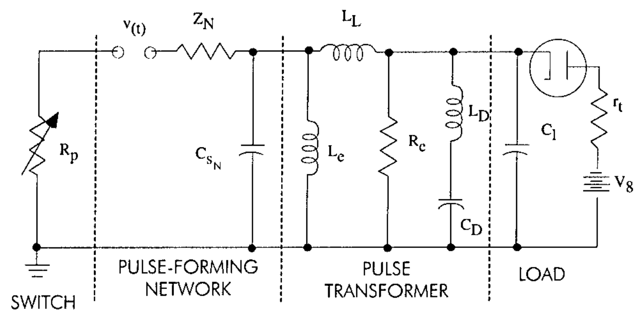
$$\text{In both cases: } \quad P_l = \frac{V_0^2}{4Z_0}$$

Figure 8

To provide even better impedance matching capabilities for really nonlinear loads, as in the magnetron treated in simplistic fashion in Fig. 8, an additional power conditioning component can be added, in the form of a Pulse Transformer, as shown in Fig. 9, which shows a relatively complete Line-Type PPS, complete with switches, a CB-based PFN, and impedance-matching Pulse Transformer, hooked up to a nonlinear HPM-type DEW source.

Line Type Pulser - Power

Equivalent discharging unit for a complete line type pulser

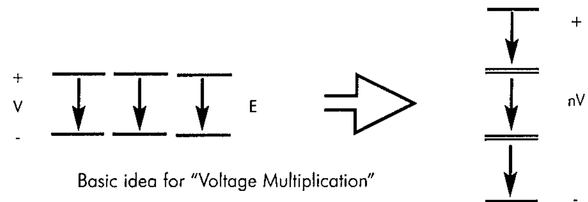


Pulse transformer needed to efficiently deliver the power to a high impedance load.

Figure 9

Having introduced the more common *lumped element* PFN, starting with the transmission line PFL, we can now introduce *voltage multiplication* by means of another lumped element concept analogous to the Blumlein multiplier circuit, which uses a set of concentric transmission lines for voltage doubling. This is a very common type of pulse generator, or pulser concept, called a Marx Generator, a series of circuits with the general characteristic of charging a bank of capacitors initially connected in parallel, thereby each having the same charging voltage, and then discharging the bank by re-connecting the capacitors in series by a set of high-voltage switches (as simultaneously as possible), thereby having their voltages add for a large output voltage and current. This is shown schematically in Figs. 10 and 11. In Fig. 10, the basic Marx voltage multiplication circuit idea just described, is shown along with the two most prevalent *discrete* (lumped) and *distributed* (transmission line) circuit types are listed. In Fig. 11, a typical "Marx Bank" circuit is shown. In the latter, when the switches S_1 through S_4 are open, one can see that the individual capacitors in the CB are connected in *parallel* across the charging voltage source V_0. Then, when the switches S are triggered (theoretically) simultaneously, the capacitors are connected in *series*, and their individual voltages *add*, leading to the sum of their voltages, V, being applied across the load. The capacitances and inductances shown connected by dashed lines are *stray* values that result from the connecting wires and other leakage or coupling paths, and these contribute so much to the overall parameters of the Marx Bank, that they usually play a pivotal role in the design and operation of the pulser and, hence, must be taken into account either theoretically or experimentally (preferably both), when a Marx Generator is built.

Voltage Multiplication



Basic idea for "Voltage Multiplication"

- Discrete Elements (Capacitors)
  Multiple Switches
  - Marx Generator
  - LC-Inversion Generator
- Distributed Elements (Transmission Lines)
  Single Switch
  - Blumlein Generator
  - Spiral Generator

Figure 10.

Voltage Multiplication - Marx Generator

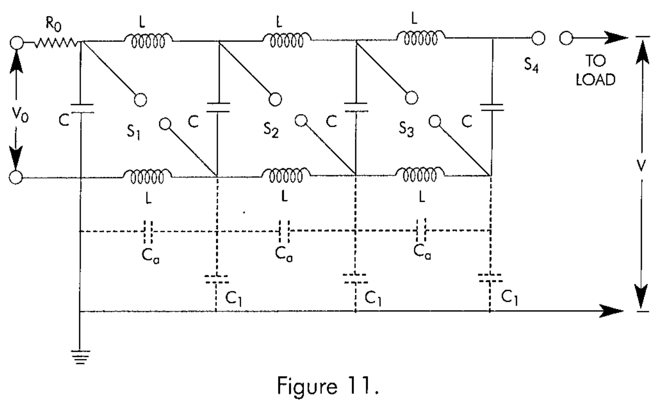
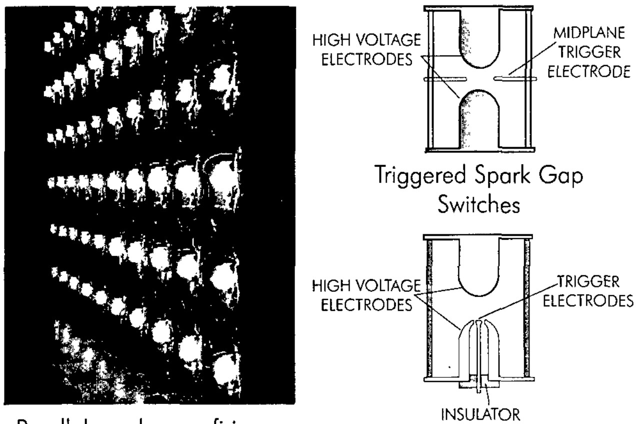


Figure 11.

The switches used in Marx Generators are usually spark gaps, which, despite their long history of troublesome operation, still provide both the speed and power handling required of the very high voltage machines needed for DEW (and many other) applications. In actual operation, simultaneous operation of a series of spark gaps is problematical (they provide much of the "stray" (C_a and C_1) capacitance shown in Fig. 11, and also interact both electrically and optically through UV radiation from the "sparks"), and output pulse "jitter" results in not very repeatable waveforms. Typical triggerable spark gap switch designs and their opera-

tion in a 2 Megajoule CB are shown in Fig. 12 below (courtesy of Ihor Vitkovitsky, from his book "High Power Switching," Van Nostrand-Reinhold Co., 1987):



Parallel spark gaps firing a 2 MJ capacitor bank

Figure 12.

The universe of high-power switches is illustrated in Fig. 13 below, where it is seen that the power handling capability of these types of switches varies as their main switching medium goes from the solid to liquid to gaseous to plasma states, depending on their energy or current density handling requirements.

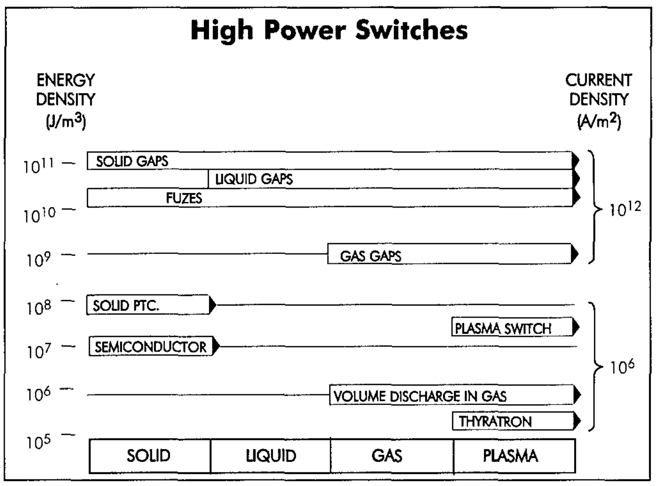


Figure 13.

Thus, it can be seen that we have come "full-circle" (or "full-circuit"); to connect our Pulse Power Subsystem into the full DEW System, as can be seen by a diagram of an HPM System from our last article on RF-DEWs, recreated in Fig. 14:

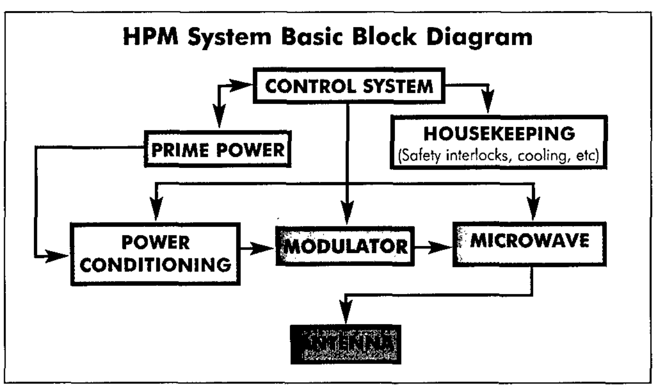


Figure 14

Pulse Power for DEWs - Explosive-Driven Pulse Generators

As a last topic, we shall treat the special case of Explosively-Driven Pulse Generators (XPGs). These are variously termed "Magnetic Flux Compression Generators" (MFCGs), "Magneto-Cumulative Generators" (MCGs), or by any number of other terms, mostly depending on the country of origin, historically. The basic principles of MFCGs are stated and illustrated in Fig. 15 below:

(MFCGs) - Basic Principles

- Magnetic Flux, $\Phi = LI$, provided by a "seed field" power supply (battery, capacitor, etc.) is trapped between the armature (inner conducting cylinder surrounding explosive) and outer stator (coil, helix, etc.) and is compressed as detonation proceeds from left to right
- Since the total flux is conserved or remains constant during the compression time, i.e., initial flux = final flux, or $L_0 I_0 = L_f I_f$, then the shrinking inductance, L, due to reduction in coil length is accompanied by an equally increasing current, I, giving the huge output pulse

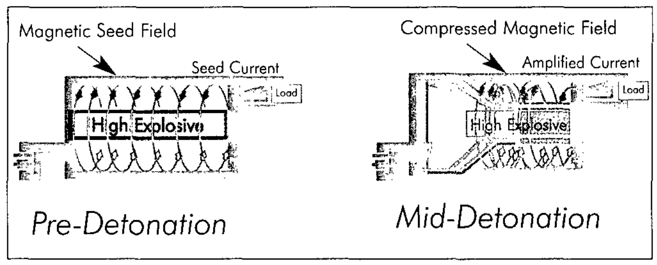


Figure 15

A number of possible geometries of MFCG designs are possible, as shown in Fig. 16 below:

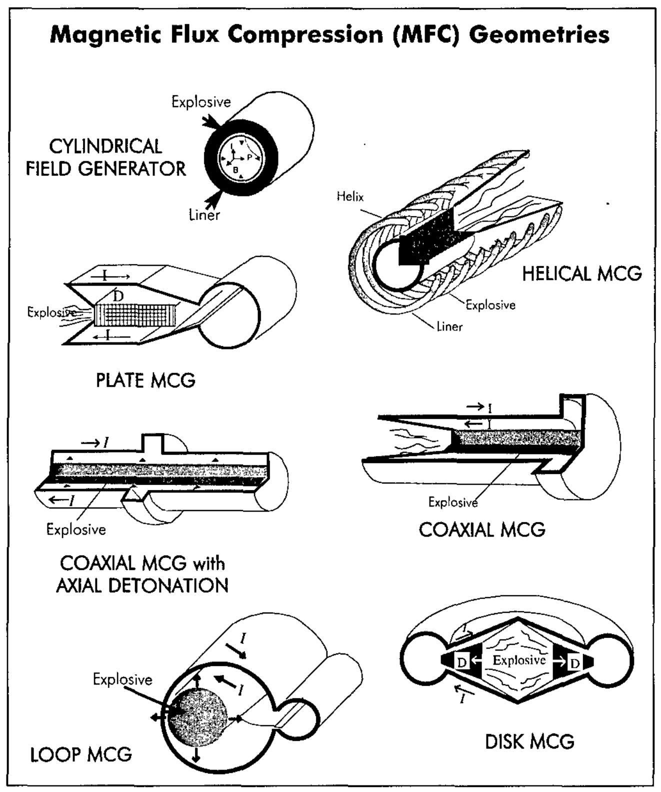


Figure 16

Each has its own advantages and disadvantages; however, the coaxial and helical MFCGs are the most commonly used designs. Their pros and cons are compared in Fig. 17.

MFCGs - Coaxial or Helical?

- Coaxial generator physics quite well understood
  - Output current calculation successful if current diffusion, ohmic heating, etc. is taken into account
- Coaxial generator has small theoretical current gain due to small initial inductance.
- Most coaxial generators are centerline detonated - expensive

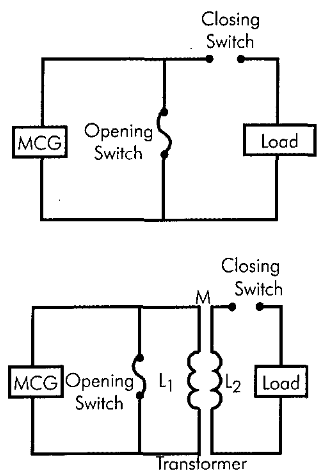
- Helical generator physics less well understood
  - Output current calculation unsuccessful if same physical mechanisms as for the coaxial generator are taken into account
- Helical generator has large theoretical current gain due to large initial inducatance (gain: 100s.....1000s)
- Helical generators are relatively cheap to build and assemble

Figure 17

Even MFCGs (especially because of their high-current, relatively low-voltage outputs) also must match their output impedances to their respective DEW loads, and normally, a power conditioning element must therefore be inserted in between the MFCG and the load, usually in the form of a pulse transformer or, at the minimum, a fuzable link or switch, as shown in Fig. 18:

By now, it is hoped that the reader should recognize familiar components and subsystems in these examples that Pulse Power engineers utilize in their designs, regardless of the prime power source - whether conventional or explosive-driven - for a myriad of DEW applications. Ultimately, the biggest challenge facing the Pulse Power scientists and engineers, is whether or not they can tailor the Pulse Power Subsystem to fit the platform and the operational parameters, in order to accomplish their intended mission.

MFCGs Power Conditioning



Basic inductive energy storage

Two basic schemes to alleviate the basic problem with MFCGs: they produce large currents and rather low voltages

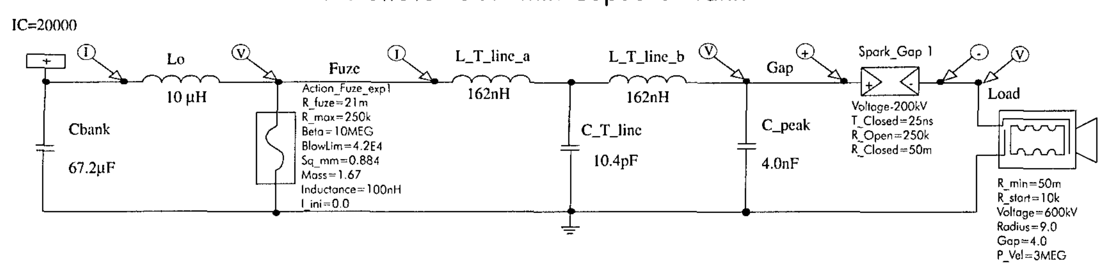
Inductive energy storage with transformer

Figure 18

A numerical example of a typical MFCG schematic circuit for a PPS test setup is illustrated in Fig. 19, compared with an equivalent CB pulser, both powering an HPM load (courtesy of Dr. Magne Kristiansen of Texas Tech University). A physical configuration of an AF laboratory PPS powering a Klystron HPM source is illustrated in Fig. 20.

MFCGs - Test Circuit with HPM Source Load

Microwave Pulser with Capacitor Bank



Microwave Pulser with Explosive Generator

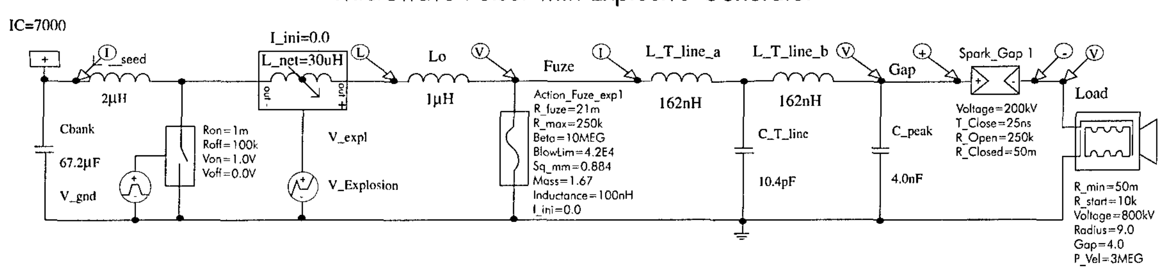


Figure 19

Banshee Pulsed Power Modulator Driving Annular Beam

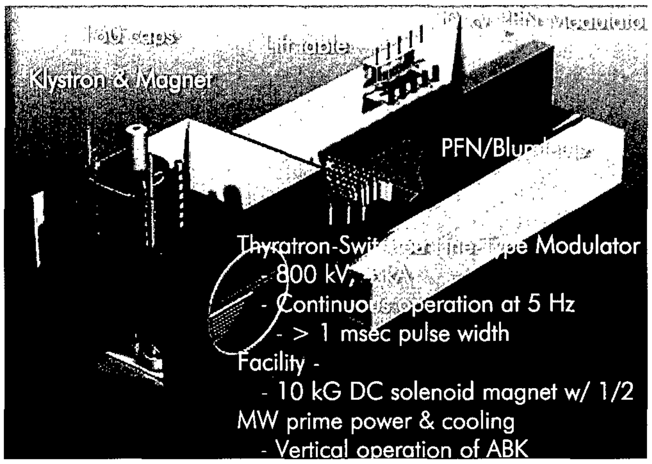


Figure 20

About the Author:

Dr. Edward P. Scannell, WSTIAC Chief Scientist, is an experimental physicist with over 30 years of experience in a broad range of technical areas, in both conducting and managing research and development programs. He received his B.S. in Physics from Tulane University in 1965, and his Ph.D. in Physics from North Carolina State University in 1976. His areas of technical expertise include: plasma physics; alternative energy sources, such as controlled fusion, magnetohydrodynamic (MHD) generators, nuclear isomers, and fuel cells for both large scale industrial and compact military applications; electromagnetic (EM) accelerators for EM guns, space propulsion and nuclear weapons simulation; and high power microwave (HPM), particle beam, laser and pulse power physics for directed energy (DE) applications.♦

Report from the AIAA 3rd Biennial National Forum on Weapon Systems Effectiveness

The American Institute of Aeronautics and Astronautics (AIAA) 3rd Biennial National Forum on Weapon Systems Effectiveness was held 18-20 November 2003 at the Boeing Company in Seal Beach, CA. This classified Forum was organized by the AIAA Weapon Systems Effectiveness Technical Committee.

The Forum featured technical sessions that covered the Future Combat Systems (FCS), ballistic missile defense systems, naval weapon systems, weapons of mass destruction mitigating solutions and technologies, emerging technologies, laser weapon systems and technologies, and test and evaluation for weapon systems. Two keynote talks discussed the military effectiveness of U. S. weapon systems, such as JDAM, JSOW, Hellfire and the GBU-16 Laser Guided Bomb. MG James Amos, Commanding General, 3rd Marine Aircraft Wing, discussed the use and effectiveness of advanced weapon systems during Operation Iraqi Freedom, and Lt Col Harry Conley, Chief, System Analysis Branch, USAF Air Combat Command, discussed the effectiveness of air-to-ground weapons during Operation Enduring Freedom in Afghanistan. The Honorable Phil Coyle, Senior Advisor, Center for Defense Information, and former Director of Operational Test and Evaluation, Office of the Secretary of Defense, gave a keynote talk that presented his personal views on the measurement of BMD systems effectiveness. Dr. Sandra Slivinsky, Air Force Research Laboratory, gave a keynote talk that described the future of prompt global strike and showed how the Common Aero Vehicle will permit us to perform a variety of future precision deep strike missions.

Many technical papers of interest to WSTIAC users were presented at the Forum, including papers on topics such as FCS military operational effectiveness, unmanned ground vehicle technology, survivability/lethality modeling, integrated C4ISR for networked fires, anti-jam techniques for improving guided weapon performance, Aegis BMD testing, novel penetrator lethality, naval surface fire support, countermeasures to chemical and biological weapons, miniature kill vehicle system effectiveness, penetrator guidance technologies, advances in electromagnetic launch technologies, impact of UCAVs on future airpower, guidance techniques for improving performance against separating BMD targets and laser bioeffects, among others. The progress being made in tactical high energy lasers was quite impressive, as evidenced by the papers that described the Mobile Theater High Energy Laser (MTHEL) and the Advanced Tactical Laser ACTD.

Dr. James Walker, Southwest Research Institute (SwRI), gave a very interesting talk that described debris impact testing and analysis performed by SwRI, NASA and others in support of the Columbia Accident Investigation Board. The SwRI/NASA tests showed that the shuttle wing leading edge could be severely damaged by foam debris striking it under conditions consistent with those occurring during the Columbia STS 107 launch. The damage observed in these tests was not all that surprising since the foam delivered more than five times the kinetic energy and twenty times the momentum of a Springfield 30-06 hunting rifle bullet fired at point blank range.

Forum participants were given an opportunity to tour the Boeing C-17 Globemaster production line in Long Beach. The C-17 employs a "supercritical" wing designed to delay and reduce the drag rise at high subsonic speeds, thus enhancing fuel efficiency and speed. This aircraft can rapidly deliver more than 100 troops or approximately 85 tons of cargo to main operating bases or forward bases in a deployment area. C-17s have recently supported U. S. deployments during Operation Enduring Freedom and Operation Iraqi Freedom and in the future are expected to transport the Future Combat Systems.

The classified proceedings from this AIAA Forum are expected to be available in February 2004 from the Defense Technical Information Center, 8725 John J. Kingman Road, Suite 0944, Ft. Belvoir, VA 22060-6218. Requesters must be registered DTIC users and must also be approved to access classified information.

Dr. Wes Kitchens
Vice President, Hicks and Associates
McLean, VA
(703) 676-6292

Editor's Note: Dr. Kitchens served as Director of WSTIAC 2000-2002.

in the news...

HYBRIDS ON THE HIGH SEAS: FUEL CELLS FOR FUTURE SHIPS

As hybrid electric cars become more commonplace on America's highways, the Navy is working to bring hybrid electric ships to the high seas. The Office of Naval Research is developing innovative propulsion systems based on new fuel-cell technology for efficient generation of electrical power - and greater design flexibility - for future ships.

To ensure a relatively quick transition to this promising technology, ONR is funding development of a method to extract hydrogen from diesel fuel. A diesel reforming system would take advantage of the relative low cost of the fuel and the Navy's established infrastructure for buying, storing, and transporting it.

Unlike gas turbines and diesel engines, fuel cells do not require combustion, and therefore don't produce pollutants such as nitrogen oxide. Fuel cells are also far more efficient than combustion engines. ONR program officer Anthony Nickens explains that "the Navy's shipboard gas-turbine engines typically operate at 16 to 18 percent efficiency because Navy ships usually sail at low to medium speeds that don't require peak use of the power plant. The fuel cell system that ONR is developing will be capable of between 37 to 52 percent efficiency."

Moreover, fuel cells will permit design of a "distributed" power system, since unlike conventional engines, they can be dispersed throughout the ship instead of being co-located with the ship's shaft. This added flexibility will improve ship survivability. Nickens says that the Navy's DD(X) land-attack destroyer program is very interested in fuel cell technology as a supplemental power source. Fuel cells combine improved efficiency, low emissions, and design flexibility, all of which help slash shipbuilding costs - a bottom-line goal of the Navy's current "transformation" efforts.

ONR is testing a 500-kilowatt diesel fuel reformer, or "integrated fuel processor," that is compatible with a proton exchange membrane (PEM) fuel cell, at the Department of Energy Idaho National Engineering and Environmental Laboratory in Idaho Falls. Reforming diesel is especially tricky due to the sulfur present in the fuel. The integrated fuel processor heats and vaporizes the diesel, then the sulfur in it is converted into hydrogen sulfide. The hydrogen sulfide is then exposed to zinc oxide, oxidizing the sulfur into sulfur dioxide, and separating it from the hydrogen.

The testing will continue through June 2004 to prove out the reforming process. Meanwhile, ONR is looking at design approaches to reduce the size of the processor, which consists of an arrangement of valves, water-gas shift reactors, an oxidizer, and other components, so that it won't take up too much space on a Navy ship.

Office of Naval Research Ed Walsh, 703-588-1010; e-mail: Edward_Walsh@onr.navy.mil.

THAAD Name Change

The Theater High Altitude Area Defense (THAAD) System has undergone a name change to more accurately reflect its position in the multi-layered Ballistic Missile Defense System (BMDS). The "T" in THAAD will now stand for "Terminal," indicating its position as a terminal element of BMDS. THAAD is designed to intercept targets as they enter the terminal, or last, phase of a ballistic trajectory. The name change was directed last week in a decision by Lt. Gen. Ronald Kadish, director of the Missile Defense Agency.

THAAD is the only missile system specifically designed to intercept and destroy incoming ballistic missiles both inside and outside the earth's atmosphere. The program will be entering its next phase of flight testing at White Sands Missile Range later this year.

Missile Defense Agency Terminal High Altitude Area Defense Project Office Huntsville Ala. (256) 842-0561 – Pam Rogers

ARMY ANNOUNCES INITIAL RESULTS OF AVIATION REVIEW

The Army announced today the initial results of its ongoing review of Army aviation. The comprehensive review has produced several strategic recommendations that will be acted on now to ensure Army aviation meets the current and future challenges of an evolving operational environment and incorporates lessons learned from the Global War on Terrorism.

The review and lessons learned from the last two and a half years of war reinforce recent decisions to make the Army more joint and expeditionary with balanced and integrated capabilities between the Active and Reserve Components. Army formations are currently transforming into more lethal, agile, modular, strategically flexible and cohesive units that can train, deploy and fight together in full-spectrum operations.

Lessons learned and the aviation review also reemphasized the importance of maintaining versatile and survivable aviation formations that are effective in both combat and stability operations. Therefore, the Army must replace and recapitalize its current helicopter fleet to increase aircraft survivability, sustainability and operability.

Army Aviation will restructure in order to: accelerate air crew protection and Aircraft Survivability Equipment (ASE) initiatives to meet the evolving threat and provide every aircraft with the best possible equipment; modernize approximately 1,400 helicopters to extend aviation capabilities beyond 2020; transform Reserve Component aviation; purchase approximately 800 new aircraft; accelerate the Unmanned Aerial Vehicle (UAV) program to add platforms that extend battlefield awareness and strengthen manned-unmanned teaming; and balance current and future Army Aviation capabilities.

The President and the Secretary of Defense have approved the Army's recommendation to submit a budget amendment to Congress for the FY '05 budget request that would allow the Army to terminate the Comanche program and reallocate approximately $14.6 billion (FY 04 – 11) to restructure and revitalize Army aviation to meet current and future needs. This important Army recommendation was made after months of comprehensive studies and consideration of numerous alternatives.

Reallocated funds and aviation restructure will also allow the Army to pursue Joint aviation programs, modularize and standardize aviation formations across the Active and Reserve Components, and accelerate the resourcing of the Army's tactical UAV programs. This also requires the industrial base to increase its production capability to meet the Army's requirements for new and modernized aircraft. The net result of this reallocation will be the new purchase, upgrade, recapitalization, or modernization of over 70 percent of the rotary winged fleet.

Strengthening Army aviation reaffirms and energizes the Army's commitment to Department of Defense and Army Transformation and Future Combat System (FCS). Using resources currently allocated for 121 Comanche platforms, the Army can accelerate transformation through the next two decades to meet its aviation needs. Army Public Affairs Washington DC.

Directed Energy Weapons Course

Instructor: Dr. Edward Scannell, WSTIAC

Location: Huntsville, Alabama
6 April, 27 July, 30 November 2004
(Course starts at 0800 and ends at 1700 hours)

Course Description:

This one day short course provides an introduction to the basic principles and techniques of Directed Energy Weapons (DEWs). Weapon system applications will also be thoroughly analyzed. The technologies behind each type of DEW will be examined, and the critical path components will be identified and explored with respect to their effect on future DEW development. In addition, advantages that can be achieved by employing DEWs will be discussed, as well as the status of DEW developments and deployments in the international arena. The key DEW programs in High Energy Lasers and RF-DEWs or High Power Microwaves will be fully described.

This short course is provided by the Weapon System Technology Information Analysis Center (WSTIAC). It will be of great benefit to people who need to understand the basic concepts, technologies, design requirements and practical applications of DEWs, including program and business managers, political decision makers, engineers, scientific researchers and military personnel. An undergraduate technical degree is recommended. Mathematics is kept to a minimum, but important formulas are introduced.
These and many other critical questions will be examined:

- What is Directed Energy and what are the different types of Directed Energy Weapons?
- What are the advantages and disadvantages of each type of DEW and what are their target effects and tactical and strategic capabilities?
- How do DEWs work and what are the critical technologies that must be developed for their eventual use in practical systems?
- How may threat DEW effects be countered and how can we protect our own systems?
- What are the major U.S. and international DEW programs that are being pursued?
- What is the prognosis for future DEW development?

About the Instructor:

Dr. Edward Scannell is a senior member of Alion's technical staff and also serves as WSTIAC's Chief Scientist. Dr. Scannell was Chief of the Directed Energy and Power Generation Division of the U.S. Army Research Laboratory. He has over 30 years of experience in technical areas related to DEWs, including: plasma physics; conventional and alternative energy sources, electromagnetic (EM) guns, particle beam, laser, high power microwave (HPM), and pulse power physics.

Security Classification:

The information presented is kept at the unclassified level, but is designated FOR OFFICIAL USE ONLY (FOUO) and is export controlled. The security classification of this course is SECRET (U.S. citizens only) to facilitate discussions.

Fee:

The registration fee for this one day course is $700 for U.S. government personnel and $800 for government contractors. Contractor teams of 3 or more, registered at the same time, are charged $700 per person.

Handout Material:

Each student will receive a comprehensive set of course notes covering the material presented.

Training Location:

The course is taught at 215 Wynn Drive, Suite 101, Huntsville. AL 35805

For additional information, contact:
Mrs. Kelly Hopkins, Seminar Administrator,
at (256) 382-4747, or by e-mail
khopkins@alionscience.com

Notice: WSTIAC reserves the right to cancel and/or change the course schedule and/or instructor for any reason. In the event of a schedule change or cancellation, registered participants will be individually informed.

Introduction to Sensors and Seekers for Smart Munitions and Weapons Course

Instructor: Paul Kisatsky or Mark Scott, WSTIAC

Location: Huntsville, Alabama

2-4 March, 25-27 May, 17-19 August, 28-30 September 2004

(Course starts at 0800 Tuesday and ends at 1630 Thursday)

Course Description:

This 3-day course provides an introduction to the most commonly used sensors and seekers employed in smart munitions and weapons (projectiles, missiles and wide area mines). It is oriented to managers, engineers, and scientists who are engaged in smart weapons program development and who desire to obtain a deeper understanding of the sensors they must deal with, but who do not need to personally design or analyze them in depth. An undergraduate technical degree is recommended. Mathematics is kept to a minimum, but important formulas are introduced. This course also provides an excellent foundation for those scientists and engineers who desire to pursue this discipline to intermediate and advanced levels.

The course covers:

- Classification of seekers and sensors
- Fundamentals of waves and propagation
- Fundamentals of noise and clutter
- Fundamentals of search footprints
- Introduction to infrared
- Introduction to radar
- Introduction to ladar
- Introduction to visionics
- Introduction to acoustics
- Future projections and interactive brainstorming

Noise and clutter, the predominant obstacles to success in autonomous seekers, are given emphasis. The major sensor types are classified and each is discussed. In particular, infrared, radar, optical laser radar (ladar), imaging and non-imaging, and acoustic sensors are individually covered. Of special interest is the discussion on human visionics versus machine recognition, since this concept is of central importance to understanding autonomous versus man-in-the-loop sensing systems. The implications of "artificial intelligence", "data fusion", and "multi-mode" sensors are also briefly discussed. System constraints, which force tradeoffs in sensor design and in ultimate performance, are also covered. Time permitting, a projection of future trends in the role of sensors for smart munitions will be presented, followed by a "brain-storming" session to solicit student views.

About the Instructors:

Both Paul Kisatsky and Mark Scott are Senior Technology Scientists with Alion Science and Technology. They are recognized as Subject Matter Experts on sensors and seekers for smart munitions and weapons and both have more than 25 years of hands-on experience in sensors and seekers analysis of modern smart munitions and weapons.

Security Classification:

This course is unclassified.

Training Location:

The course is taught at 215 Wynn Drive, Suite 101, Huntsville, AL 35805.

Fee:

The registration fee for this 3-day course is $950 for U.S. government personnel and $1150 for government contractors. Contractor teams of 3 or more, registered at the same time, are charged $950 per person.

Handout Material:

Each student will receive a comprehensive set of course notes covering the material presented.

For additional information, contact:
Mrs. Kelly Hopkins, Seminar Administrator,
at (256) 382-4747, or by e-mail
khopkins@alionscience.com

Notice: **WSTIAC reserves the right to cancel and/or change the course schedule and/or instructor for any reason. In the event of a schedule change or cancellation, registered participants will be individually informed.**

Weaponeering Course

Instructor: Professor Morris Driels, US Naval Postgraduate School

Location: Huntsville, Alabama

20-22 April, 31 August-2 September, 7-9 December 2004

(Course starts at 0800 Tuesday and ends at noon Thursday)

Course Description:

This 2½-day short course is based on a very successful graduate-level weaponeering course developed by Professor Driels and taught at the Naval Postgraduate School(NPS), Monterey, CA. The course will provide an overview of the fundamentals of the weaponeering process and its application to air-to-surface and surface-to-surface engagements. The course explains the analytical basis of current weaponeering tools known as the Joint Munitions Effectiveness Manuals (JMEMs) produced by the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME). The JMEMs are used by all Services to plan offensive missions and allow the planners to predict the effectiveness of selected weapon systems against a variety of targets.

The short course is divided into three parts.

Part I covers the basic tools and methods used in weaponeering:

- The weaponeering process
- Elementary statistical methods
- Weapon trajectory
- Delivery accuracy of guided and unguided munitions
- Target vulnerability assessment

Part II covers the weaponeering process for air-launched weapons against ground targets:

- Single weapons directed against point and area targets
- Stick deliveries (point and area targets)
- Projectiles (guns and rockets)
- Cluster munitions
- Weaponeering for specific targets: bridges, buildings, etc.)
- Collateral damage modeling

Part III covers the weaponeering process for ground engagements:

- Indirect fire systems - artillery and mortars.
- Direct fire systems - infantry and armored vehicles.
- Mines - land and sea.

About the Instructor:

Professor Driels is a Professor of Mechanical Engineering at the U.S. Naval Postgraduate School in Monterey, California. He has worked with the JTCG/ME on a variety of topics in support of the JMEMs for a number of years. He has taught a quarter-long weaponeering course at NPS for three years and is preparing a text book on the subject.

Security Classification:

The course is unclassified.

Training at Your Location:

WSTIAC can conduct this course at your location to reduce your travel time and cost. Please call Mrs. Kelly Hopkins to discuss.

Fee:

The registration fee for this 2½-day course is $950 for U.S. government personnel and $1150 for government contractors. Contractor teams of 3 or more, registered at the same time, are charged $950 per person.

Handout Material:

Each student will receive a comprehensive set of course notes covering the material presented.

For additional information, contact:
Mrs. Kelly Hopkins, Seminar Administrator,
at (256) 382-4747, or by e-mail
khopkins@alionscience.com

Notice: WSTIAC reserves the right to cancel and/or change the course schedule for any reason. In the event of a schedule change or cancellation, registered participants will be individually informed.

Smart/Precision Weapons Course

Instructors: Mr. Hunter Chockley and Mr. Mark Scott, WSTIAC

Location: Huntsville, Alabama

17-19 February, 30 March-1 April, 11-13 May, 13-15 July, 19-21 October, 16-18 November 2004

(Course starts at 0800 Tuesday and ends at noon Thursday)

Course Description:
This 2½-day short course provides a general understanding of smart weapons and related technologies. This course is aimed at providing general knowledge about smart weapons technology and a source of current information on selected U.S. and foreign smart weapons, to include system description, concept of employment, performance characteristics, effectiveness and program status.

A variety of ground, sea and air smart/precision weapon systems are discussed, to include fielded and/or developmental U.S. systems such as Joint Direct Attack Muniion (JDAM), Joint Air-to-Surface Standoff Missile (JASSM), Javelin, Line-of-Sight Anti-Tank (LOSAT), Excalibur, Extended Range Guided Munition (ERGM), Common Missile, Tomahawk, Standoff Land Attack Missile - Expanded Response (SLAM-ER), Cluster Bomb Munitions and Non Line of Sight - Launch Systems, among others, as well as representative foreign smart/precision weapons.

The objective of this course is to inform materiel and combat developers, systems analysts, scientists, engineers, managers and business developers about smart/precision weapons, to include:

- State of the art of representative U.S. and foreign smart weapons systems;
- Employment concepts;
- Smart weapons related systems, subsystems, and technologies; and
- Technology trends.

About the Instructors:
Mr. Mark Scott and Mr. Hunter Chockley are Science Advisors with Alion. Each instructor has more than 25 years of experience with weapons technology and/or smart/precision weapons. They have conducted advanced concept studies, weapon system/subsystem analyses and comparison of alternatives, subsystem assessments to include Seekers /Sensors, CM/CCM, and simulation/analysis tool development.

Security Classification:
The information presented is kept at the unclassified level, but is designated FOR OFFICIAL USE ONLY (FOUO) and is export controlled. The security classification of this course is SECRET (U.S. citizens only) to facilitate discussions.

Training Location:
The course is taught at 215 Wynn Drive, Suite 101, Huntsville, AL 35805

Fee:
The registration fee for this 2½-day course is $950 for U.S. government personnel and $1150 for government contractors. Contractor teams of 3 or more, registered at the same time, are charged $950 per person.

Handout Material:
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For additional information, contact:
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Notice: WSTIAC reserves the right to cancel and/or change the course schedule and/or instructor for any reason. In the event of a schedule change or cancellation, registered participants will be individually informed.

Calendar of Events

Upcoming Conferences and Courses

March 2004

15-18 March 2004
2004 Joint Undersea Warfare Technology Spring Conference
"Understanding the Littoral Undersea Warfare Challenges"
SECRET/NOFORN
Naval Postgraduate School
Monterey, CA
For additional information
Email: kwilliams@ndia.org
http://register.ndia.org/interview/register.ndia?PID=Brochure&SID=_1400KR1FM&MID=4260

22-25 March 2004
2004 Interoperability and Systems Integration Conference
Denver, CO
For additional information
Email: pedmonson@ndia.org
http:/register.ndia.org/interview/register.ndia?PID=Brochure&SID=_1400KR1FM&MID=4120

22-26 March 2004
2nd Missile Defense Conference and Exhibit
SECRET - US-ONLY
Washington DC
For additional information
http://www.aiaa.org/calendar/index.hfm?cal=5&luMeetingid=945

28 March-1 April 2004
10th International Conference on Robotics and Remote Systems
Gainesville, FL
For additional information
Contact Prof. Carl D. Crane III
ccrane@ufl.edu
http://urpr.nuceng.ufl.edu/March2004.htm

29-30 March 2004
Second Annual Military Fuel Cell Conference
Las Vegas NV
For additional information
http://www.ttcus.com/mfc/index.html

30-31 March 2004
Combat UAV 2004
Arlington, VA
For additional information
E-mail: info@idga.org
http://www.idga.org

29 March - 1 April 2004
DTIC Annual Users Meeting and Training Conference
Alexandria, VA
For additional information
E-mail: coninfo@dtic.mil
http://www.dtic.mil/dtic/annualconf

April 2004

13-16 April 2004
39th Annual Gun & Ammunition / Missiles & Rockets Conference & Exhibition
Baltimore, MD
For additional information
dkhan@ndia.org
http://register.ndia.org/interview/register.ndia?PID=Brochure&SID=_1400KR1FM&MID=4590

26-28 April 2004
48th Annual Fuze Conference
Technology in Fuzing
Charlotte, NC
For additional information
POC: cohara@ndia.org
http://register.ndia.org/interview/register.ndia?PID=Brochure&SID=_1400KR1FM&MID=4560

26 Apr - 29 Apr 2004
PLANS 2004
2004 IEEE Position, Location and Navigation Symposium
Monterey, CA
For additional information
http://www.plans-ieee.org/

26 April-01 May 2004
2004 IEEE International Conference on Robotics and Automation
New Orleans, LA
For additional information
http://www.icra2004.org/

29 April 2004
2004 Strike, Land Attack & Air Defense (SLAAD) Annual Symposium
Applied Physics Lab
Laurel, MD
For additional information
POC: kwilliams@ndia.org
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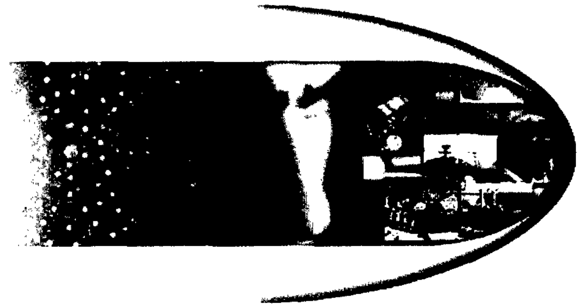

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